SIGGRAPH 2001

EXPLORE INTERACTION
AND DIGITAL IMAGES

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Homomorphic Factorization of BRDFs for High-Performance Rendering

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CGL

Outline

- Introduction
- Previous Work
- Factorized Representation
- Results
- Performance and Error
- Conclusions

Introduction

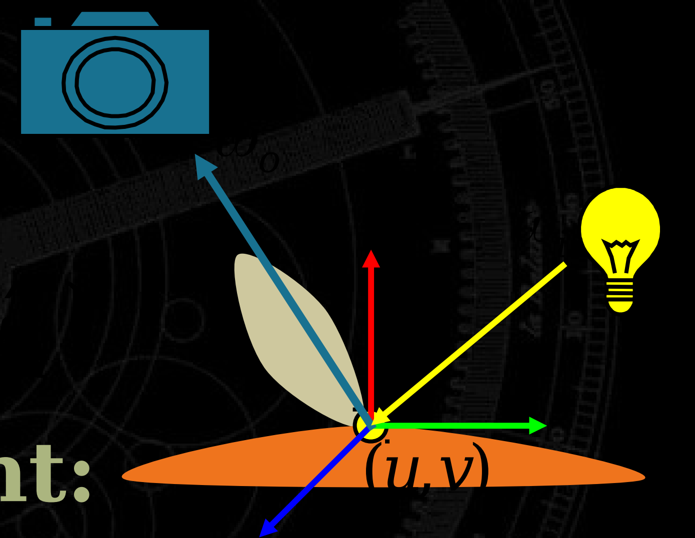
- What is a bidirectional reflectance distribution function (BRDF)?
- Why use BRDFs in real-time rendering?

BRDF

- **Functional notation:**

$f_\lambda(u,v,\omega_o,$

- **Assume shift-invariant:**



- **Omit wavelength dependence (use RGB):**

BRDF

- **Properties of physical BRDFs:**
  - Helmholtz reciprocity
  - Conservation of energy
- **BRDF classes:**
  - Isotropic
  - Anisotropic

Local Lighting Equation

- Outgoing radiance from point x in direction ω :

- Illumination from N point sources:

Previous Work

- **Basis summation**
  - Cabral et al., Bidirectional Reflection Functions from Surface Bump Maps (1987)
  - Ward, Measuring and Modeling Anisotropic Reflection (1992)
  - Lafortune et al., Non-Linear Approximation of Reflectance Functions (1997)

Previous Work

- **Environment mapping**
  - Cabral et al., Reflection Space Image Based Rendering (1999)
  - Kautz et al., A Unified Approach to Prefiltered Environment Maps (2000)
  - Kautz and McCool, Approximation of Glossy Reflection with Prefiltered Environment Maps (2000)

Previous Work

- **Factorization**
  - Fournier, Separating Reflection Functions for Linear Radiosity (1995)
  - Heidrich and Seidel, Realistic, Hardware-Accelerated Shading and Lighting (1999)
  - Kautz and McCool, Interactive Rendering with Arbitrary BRDFs using Separable Approximations (1999)

Previous Work

- **Factorization**
  - SVD approach by Kautz and McCool (1999)

Homomorphic Factorization

- Approximate *f* using product of positive factors:

- Take logarithm of both sides:

Parameterization

- **Choose parameterization:**
  - Want parameters that are easy to compute
  - *Choice* (others possible!):
- **Take logarithm:**

Data Constraints

- **Need to find *p* and *q*:**
  - Set up linear constraints relating samples in *f* to texels in *p* and *q*
  - Use bilinear weighting factors to get subpixel precision

Data Constraints

- Data constraints can be written as:

Smoothness Constraints

- **Add constraints to equate Laplacian with zero:**

  - Ensures every texel has a constraint

∀λ controls the smoothness of solution

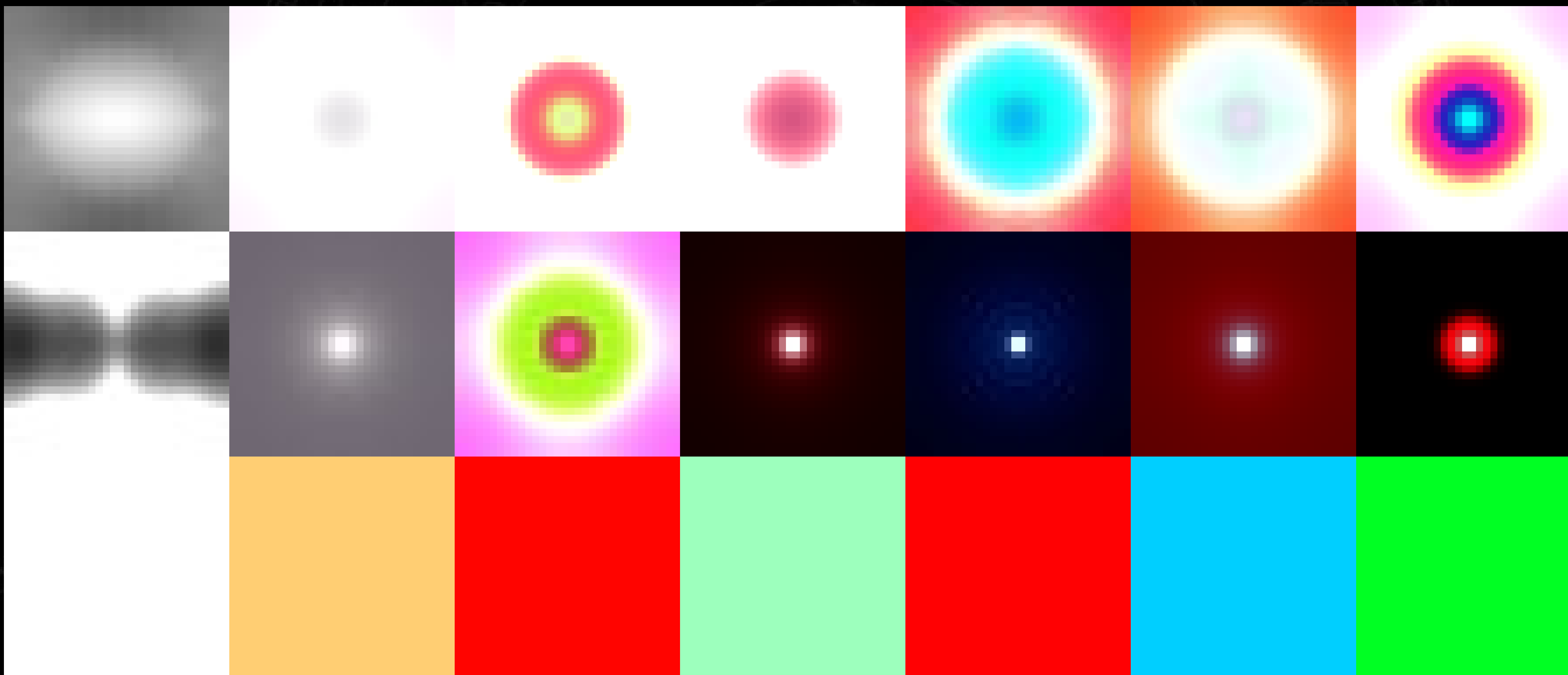
Iterative Solution

- **Solve using quasi-minimal residual (QMR) algorithm in IML++**
  - Modified conjugate-gradient algorithm
  - Freund and Nachtigal (1991)
  - Estimate an initial solution by averaging
  - Apply at sequence of increasing resolutions

Encoding into Texture Map

- Divide *p* and *q* by their maximums and combine scale factors into a single colour α
- For unit-vector-valued parameters, set up texture maps as parabolic maps, hemisphere maps, or cube maps

Results



- Top to bottom: p', q' parabolic texture maps (32 x 32) and α
- Left to right: satin (Poulin-Fournier analytic), leather, velvet (CUReT), garnet red, krylon blue, cayman, mystique (Cornell)

Rendering

- **OpenGL 1.2.1 reconstruction**
  - Multitexturing and compositing
  - e.g. NVIDIA GeForce 2 and ATI Radeon.

Rendering

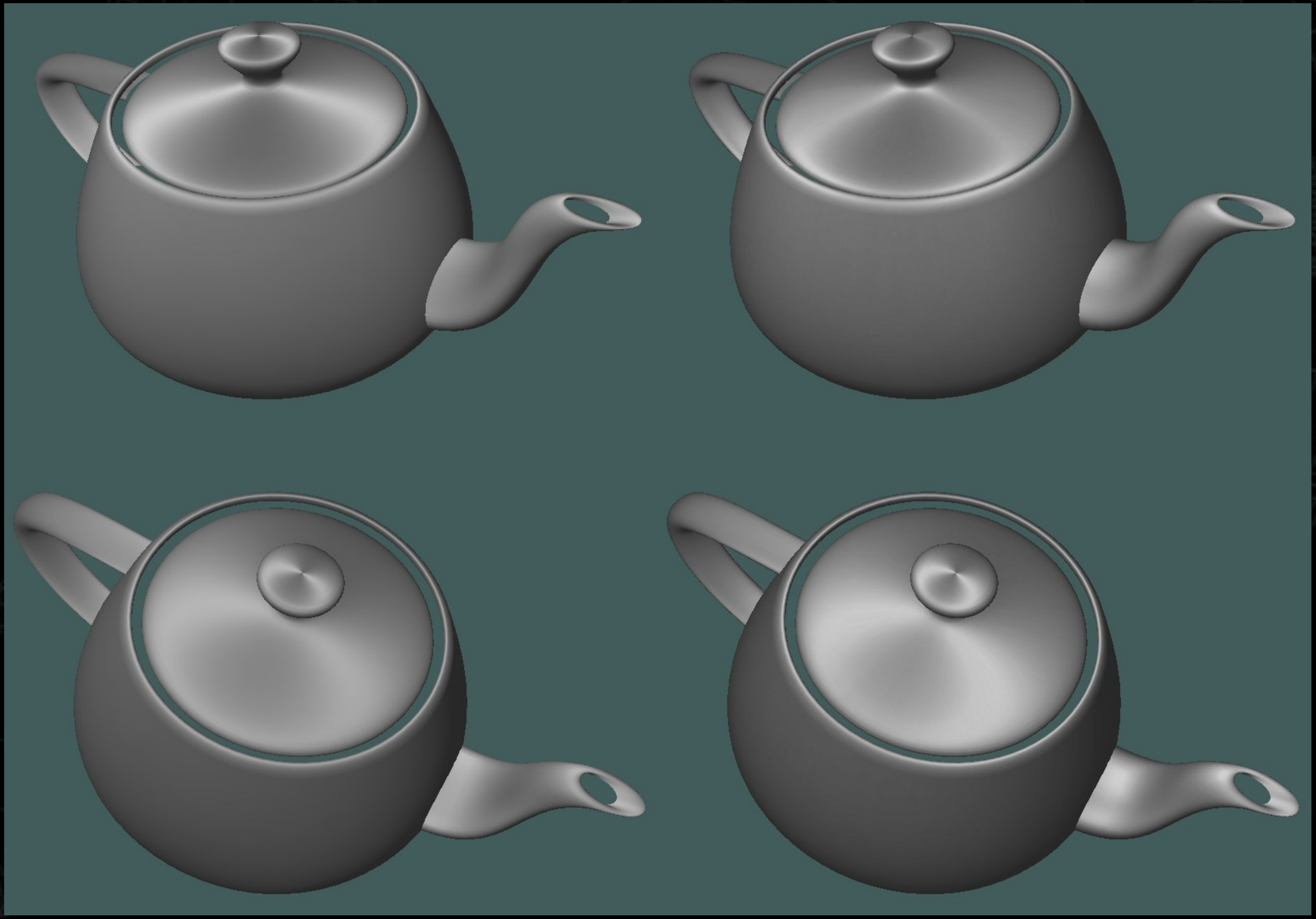
- **NVIDIA GeForce 3 reconstruction:**

  - Multitexturing and compositing
  - Register combiners
  - Vertex programs

Performance

- **Venus model with 90752 triangles**
- **Pentium III 600 MHz, 256 MB, NVIDIA GeForce 3 AGP 4x @ 1280x1024x32bit**
- **Standard OpenGL Lambertian lighting:**
  - 123 fps, 11.2 Mtri/s
- **Full illumination:**
  - 76 fps, 6.9 Mtri/s

Approximation Error



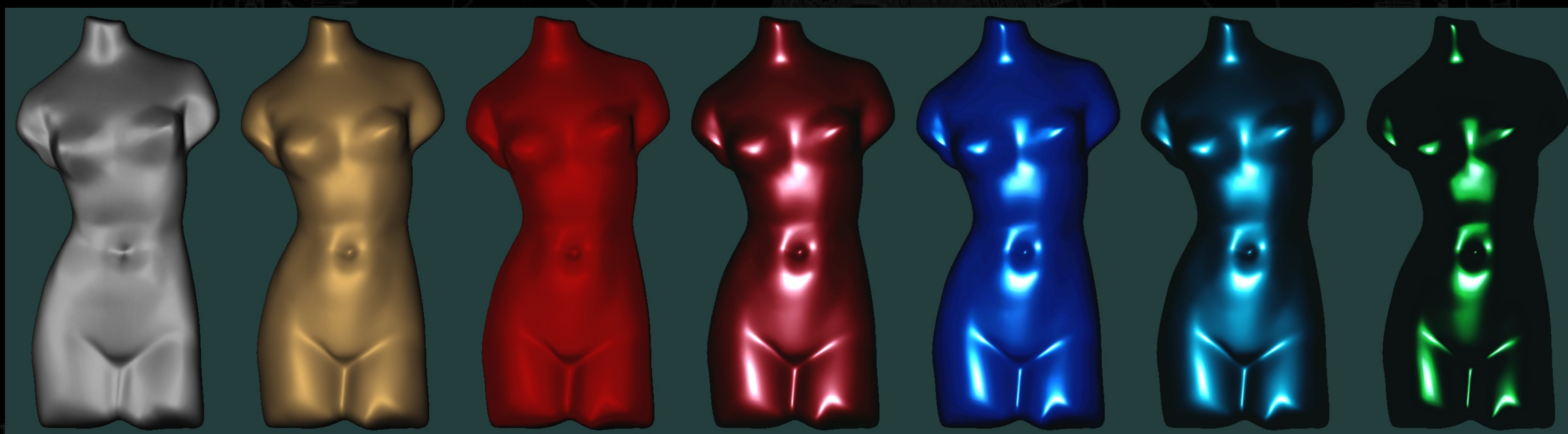
Extensions

- Other parameterizations
- Material mapping

Conclusions

- **New BRDF factorization algorithm**
  - Achieves reasonable compression ratios
  - Minimizes relative error in approximation
  - Flexible choice of parameterization
  - Results are positive factors
  - Can handle sparse data, reuse texture maps
  - Renders in real-time rates in current hardware
  - Limited to point light sources

Demo available at CAL



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